IMPACT EVOLUTION OF ICY REGOLITHS. E. Asphaug[1], J. M. Moore[1], D. Morrison[1], K. Bender[2], R. S. Sullivan[2], R. Greeley[2], P. Geissler[3], C. R. Chapman[4], and the Galileo SSI Team. ([1]NASA Ames Research Center, MS245-3, Moffett Field, CA 94035, email:asphaug@cosmic.arc.nasa.gov; [2]Arizona State University; [3]University of Arizona; [4]Southwest Research Institute.)

Evolution of regolith is poorly understood, and will remain so until we more fully appreciate the interplay of processes affecting a planetary surface. Production, comminution, transport, agglutination, segregation, sublimation, and escape of surface grains comprise a complex system that may relax into local quasi-equilibrium punctuated by cratering impacts, land-slides and other catastrophes. For example, an asteroid might for example lose most of its fine particles to space during a single cataclysmic event, with gravitationally-bound fragments forming the basis from which a new regolith can mature. A higher-gravity body on the other hand loses fines less readily, and a more mature regolith is expected — surficial equilibrium is more likely. The impactor size-frequency-velocity distribution is just as important as the target gravity, for the population responsible craters and fresh regolith also erodes crater rims and weathers the surface. A planet bombarded by a distribution of impactors biased towards large sizes is therefore expected to have a less mature regolith than one whose impactor flux consists primarily of micrometeorites.

High-resolution Galileo SSI observations of icy satellite surfaces (down to ~11 m/px for Ganymede), together with color and compositional information from SSI and NIMS and thermophysical constraints from PPR, provide a unique opportunity for a comparative understanding of regolith processes. These observations are constrained to the topmost surface layer whose optical properties (following terrain emplacement) are governed by a number of endogenic and exogenic processes which might include micrometeorite gardening, sputtering by magnetospheric particles (Johnson *et al.* 1985), photolysis, electrostatic levitation (Lee 1996), and sublimation (Spencer 1987). See Veverka *et al.* 1986 for a review of surface physics on satellites, and Schenk and McKinnon (1991) for an analysis of these processes as they may affect the optical properties of crater rays and floors on Ganymede.

The cumulative result of such processes may be responsible for the darkening of surfaces with time, a subject we now explore. In order to begin to relate crater degradation and the "weathering" of regoliths to Galileo SSI, NIMS and PPR observations, we shall first focus on micrometeorite bombardment, noting that collisions by impactors comparable in size to the regolith matrix are far different from what we have grown to expect. A coarse correlation between optical property and age (such as the terrains Uruk Sulkus and Galileo Regio on Ganymede) suggests that young, bright, bluish-white terrains might evolve over time into darker, redder surfaces due to one or more of the mechanisms just mentioned. The surface of Europa is similarly much brigher and whiter than the primordial surface of Callisto, although the youngest surfaces of Europa are blue and of a lower albedo.

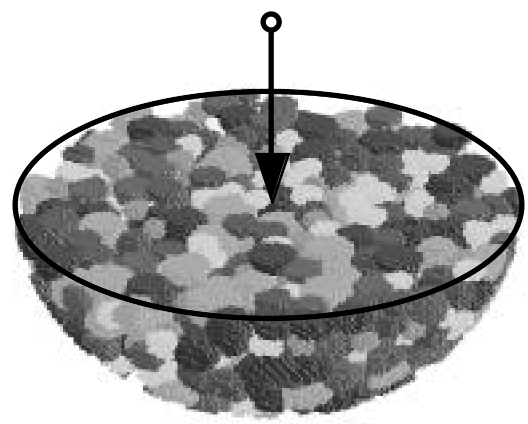

Figure 1. A 10 cm diameter 3D SPH "half-space" target consisting of "dirty" ice grains ~3 to 8 mm across (colored by size). Boundaries are sintered so the structure is rigid. Computational constraints limit the model space to a 130,000 node hemisphere, with approximately 1000 nodes per grain. A 1 mm diameter silicate sphere impacts at 40 km/s. See Benz and Asphaug 1993 or Asphaug *et al*. 1996 for details.

One model we are considering for surface albedo and color evolution (darkening and reddening with time) involves the relatively rapid brightening and whitening of a surface as emplaced flows become fractured and pulverized by impactors. After a time, the increasingly porous surface begins to serve as a very different sort of target for the small end of the impactor flux (Fig. 1) for two reasons. First, the impact (into the first target grain) is seldom at normal incidence, and when both grains are immediately vaporized, considerable momentum continues forward into the target. Second, the target provides conduits into which this resulting vapor can expand, potentially annealing grains of the deeper matrix and potentially darkening and reddening the surface. It is also possible for trapped impactor material to pollute the target directly. We have embarked upon a study these phenomena using a 3D SPH hydrocode in which individual target grains are resolved with ~1000 nodes each.

Macro-scale impactors (radii ri >> mean grain size λ) "see" a target whose pores are homogeneously distributed. Such impacts, typically associated with cratering, can often be modeled using standard hydrocode techniques (and a porous equation of state) or scaling laws (Housen et al. 1993). Meso-scale impactors (ri≈λ) and micro-scale impactors (ri<<λ), on the other hand, see a target comprised of discrete grains and interstices. Because λ and ri both play pivotal roles, nondimensional lengths (π-groups) and associated scaling laws cannot be constructed. We must therefore employ numerical techniques to understand what is going on.

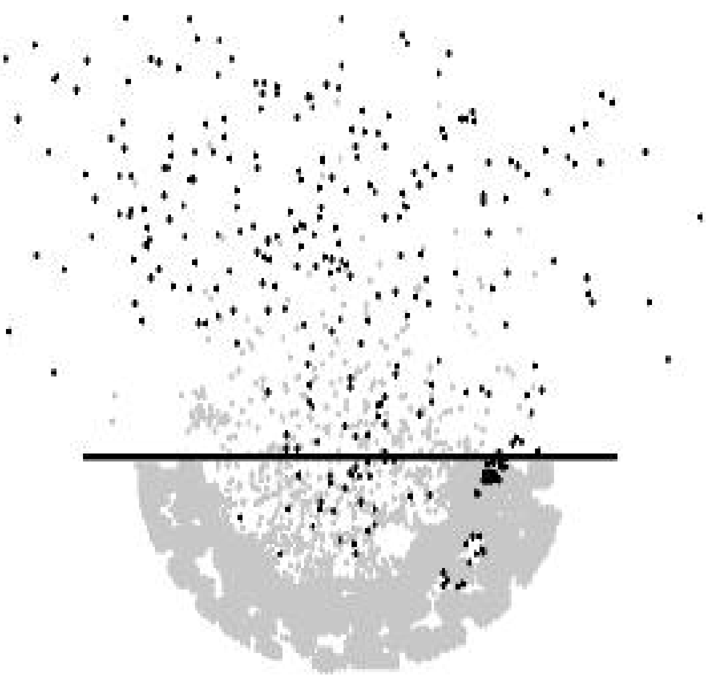

Figure 2. The same 10 cm diameter porous SPH target 16 μs after the collision of the silicate impactor (black particles) with the first target grain. This figure shows a thin slice parallel to the impact axis, where black circles represent impactor particles, grey circles represent target particles, and white space is low-density vapor (in the expansion plume) or void (in the solid matrix). The black line represents the idealized half-space plane. The fraction of impactor vapor captured in the target is consistent with the chondritic component estimated for lunar regolith (Papike *et al.* 1982).

An impact into a porous target turns out to be quite an interesting adventure for a mesoscale impactor, which strikes (and mutually vaporizes) the first grain it encounters. This vapor together with entrained melt continues forward (at a considerable fraction of the impact speed) into the deeper matrix, sometimes finding channels deep into the target. Note the cluster of black particles to the lower right in Fig. 2; another plume of vapor has found a path through the target and now (t=16μs) emerges near the surface to the right. Some vapor (not shown) has actually penetrated through the back of the target at this point, indicating that we should enlarge our calculation space. The expanding microcrater serves to crush the interstices shut behind this complex thermodynamical region.

This 3D SPH code (Benz and Asphaug 1994) employs a shock equation of state for "dirty" water ice (Lange and Ahrens 1987; Tillotson 1962) which treats the melt phase as an extrapolation between solid and vapor, and which lacks thermal conductivity. In spite of these approximations, in the early stages of this impact we can already see a strong likelihood for the role of impact vapor entrainment in regolith maturation, including grain agglutination and pollution. In upcoming work we intend to incorporate thermal conductivity together with more sophisticated equations of state (ANEOS) as they become available for water ice, and to employ faster workstations so as to be able to carry out the calculations to much later time in larger computational volumes. The simulation presented here required ~1 month on an R4400 machine.

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